SUMMARY. AN ANALYTICAL REVIEW OF DSPIN-13

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The XV Workshop on High Energy Spin Physics continued a series of meetings, the first of which was held in Dubna in 1981 on the initiative of a prominent theoretical physicist L.I. Lapidus. Since then, such meetings are taking place in Dubna each odd year. They give the opportunity to present and discuss the accumulated annual news. Another important feature is the possibility of participation for a large number of physicists from the former Soviet Union and Eastern Europe, for whom long-distance travel is difficult by financial (and in past as well by bureaucratic) reasons. In even years large International Symposia on Spin Physics have been held in various countries, including Dubna, Russia in 2012.

This meeting was characterized by a substantial attendance, with a larger than ever number of participants (125 persons) from different countries: Russia 24, USA 10, Belarus 7, Poland 6, Germany 4, Czech Republic 3, Italy 3, France 2, Slovakia 2, Iran 2, China 2 and by one person from Belgium, Bulgaria, India, Portugal, Sweden, Ukraine and South Korea. As always, a lot of physicists from JINR (53) were involved.

The reason for the increasing popularity of the meeting is, apparently, the fact that this year has brought many new experimental results and above all the discovery and determination of the quantum numbers of the Higgs boson at the Large Hadron Collider (LHC), given in talks by A. Rinkevicius (USA) and Yaquan Fang (China).

The talk by X. Artru (France) proposed the development of simple explanation of the Collins effect and the effect of handedness in the model of sequential fragmentation of quark and offered a program of implementation of the model into Monte Carlo simulation.

Classical experiments on the study of the nucleon spin structure at high energies use both scattering leptons on polarized nucleons (HERMES, JLab, COMPASS) and collisions of the polarized protons (RHIC, IHEP, JINR). The joint description of such different high-energy processes becomes possible due to the application of the fundamental theory of strong interactions, quantum chromodynamics (QCD), and its remarkable properties of factorization, local quark-hadron duality and asymptotic freedom which allow one to calculate the characteristics of a process within the framework of perturbation theory (PT). At the same time, parton distribution functions (PDF), correlations and fragmentation functions are universal and do not depend on the process. However since they are not given by the theory, they require some methods to build specific models. A number of reports at the conference were dedicated to the development and application of this type of models (P. Zavada, Czech Republic, the original covariant model of nucleon, J. Soffer, France, quantum statistical model and others). Several talks were devoted to the development of methods of experimental data processing and extraction both polarized and unpolarized PDF. It is particularly worthwhile mention the report of D. Strózik-Kotlorz (Poland) on the development of the method of truncated Mellin moments and generalized

evolution equations for these moments, and the talk of A. Sidorov (Dubna) who demonstrated the particular importance of the knowledge of quark fragmentation functions for the determination of spin dependent PDFs of sea quarks. New data of COMPASS collaboration on measurement of quark fragmentation functions into pions and kaons were presented by N. du Fresne von Hohenesche from Mainz.

The theoretical description of processes involving spin, especially dependent on internal transverse parton motion (TMD), proves to be, as always, more complicated, so that the number of these functions increases and the picture connected with them loses to a considerable degree the simplicity of a parton model with its probabilistic interpretation. One of the difficulties here is the evolution of these functions with a change in the wavelength of a tester. A possible approach to its solution was presented in the talk by I. Cherednikov (Dubna and Antwerpen).

The most widely studied to date is the helicity distribution of quarks in the nucleon g_1. The COMPASS data (A. Ivanov, Dubna) allow one essentially specify these distributions. New measurements of the structure function g_2 of the proton and neutron (^{3}He) were presented by Jian-ping Chen from JLab. They show better agreement with the so-called Wandzura-Wilczek approximation relating these distributions at leading-twist. Recent experimental data are precise enough to include in their QCD analysis not only the perturbation corrections, but also the contributions of higher-twist and target mass corrections (F. Arbabifar and F. Abdolghafari, Tehran). In this case, positive polarization of strange quarks is excluded with high probability. New data on the spin distributions of sea $\bar{u}$ and $\bar{d}$ quarks from the W^+ and W^- bosons production processes in polarized proton-proton collision were presented by the STAR collaboration (K. Barish, BNL), in good agreement with the predictions of the statistical model (J. Soffer). The polarization of gluons, however, is consistent with the results of its direct measurements by the COMPASS and PHENIX + STAR collaborations (K. Barish – BNL, Qinghua Xu – China). Its low value seems insufficient for resolving the so-called nucleon spin crisis.

The hope to overcome the crisis lies with contributions of the orbital angular momenta of quarks and gluons which can be determined by measuring the so-called Generalized Parton Distributions (GPD). Theoretical aspects of a model GPD calculation were covered in talks of S. Goloskokov (Dubna) and S. Nair (Bombay). Different experimental aspects of GPD measurement already held (HERMES) and new ones under preparation (COMPASS) were presented by W.-D. Nowak (Freiburg) and A. Sandacz (Warsaw), respectively.

Other important spin distribution functions manifest themselves in scattering of transversely polarized particles. The processes in which the polarization of only one particle (initial or final) is known are especially interesting and complicated from the theoretical point of view (and relatively simple from the point of view of experiment – such complementarities frequently occur). Such single spin asymmetries are related to the T-odd effects, i.e. they seemingly break invariance under time reversal. Here, however, we deal with an effective breaking connected not with the true non-invariance of fundamental (in our case, strong, described by QCD) interactions under the time reversal, but with their simulations by thin effects of rescattering in the final or initial state.

The effects of single spin asymmetries have been studied by theorists (including Dubna theorists who have priority in a number of directions) for more than 20 years, but their study received a new impetus in recent years in connection with new experimental data

on the single spin asymmetry in the semi-inclusive electro-production of hadrons off longitudinally and transversely polarized targets at the facilities COMPASS (F. Bradamante, A. Bressan, Trieste), HERMES (W.-D. Nowak, Freiburg) and CLAS (Jian-ping Chen, Newport News). In particular, data from HERMES for the asymmetry of pions (the so-called "Sivers function") associated with the left-right difference in the distribution of partons in a transversely polarized hadron are described by the existing theory. However, the data for positive kaons in the region of small x about 2.5 times deviate from their predictions. New measurements of the asymmetry by the COMPASS collaboration give evidence in favor of the explanation of this difference by higher-twist contributions. Especially interesting was the comparison of SSA (transversity) in the production of a pair (π^+,π^-) from transversally polarized proton: x-dependence of the pair is almost identical to the x-dependence of π^+ (F. Bradamante, Trieste), which clearly testifies to a sequential fragmentation mechanism proposed by X. Artru. New data on the SSA pions produced in polarized proton-proton collisions at RHIC energies (200×200 GeV) were provided by the STAR collaboration (Qinghua Xu, Shandong). The collaboration confirms surprisingly large asymmetries observed previously at lower energies, which indicates their energy independence. However, new measurements at large p_T show also that asymmetry has roughly constant behavior up to $p_T = 7$ GeV/c. This creates great difficulties for the modern theoretical understanding of these processes. New data were also obtained for the asymmetry of pairs of hadrons ($\pi^+\pi^-$), which creates opportunities for measuring the PDF transversity (distribution of transversely polarized quarks in a transversely polarized nucleon). Similar observations were reported by the PHENIX collaboration (K. Barish, BNL). Also, PHENIX does not see much difference in the asymmetries of η^- and π^0 mesons earlier reported by STAR. The specific mechanisms of origin of these asymmetries still remain a mystery. Thus, although in general the single asymmetry is described by the existing theory, its development continues. Appearing here T-odd PDF lose key properties of universality and become "effective" depending on the processes in which they are observed. In particular, the most fundamental prediction of QCD is a change in the sign of the Sivers function in the transition from pion electroproduction to the production of Drell-Yan pairs on a transversely polarized target. This conclusion is supposed to be checked in the COMPASS experiment (O. Denisov, Turin) and at colliders RHIC, NICA (R. Akhudzyanov, Dubna) and PANDA-PAX. We also had a very interesting talk on the importance of the Drell-Yan process and an ongoing experiment to improve our knowledge of the flavor structure of the nucleon sea (Jen Chieh Peng, Illinois).

Considerable interest and discussion were called by new data of the JLab on measurement of the ratio of the electric and magnetic form factors of the proton carried out by "technique of the recoil polarization" presented at the meeting (Ch. Perdrisat – Williamsburg, V. Punjabi – Norfolk State University). Early measurements of the JLab showed that this ratio is not constant, as it has been believed for a long time, and decreases linearly with increasing momentum transfer Q^2 (the so-called "form factor crisis"). New data obtained in 2010 (experiment GEp(3) with JINR participation), point to a flattening of this ratio in $Q^2 = 6 - 8$ GeV^2. The proposed experiment GEp(5) will advance up to $Q^2 = 15 - 17$ GeV^2. The question whether this is the behavior due to the influence of radiative corrections, in particular, two-photon exchange, is still open.

Several talks were devoted to theoretical search of Z' features and other exotic at the LHC and the future International Linear Collider (ILC) of electrons and positrons

(V. Andreev, A. Tsitrinov – Gomel).

A separate section was devoted to a problem of localization of energy momentum and spin in the classical field theory. The picture arising in geometrical description in the language of external forms is close to the traditional: if electrons (and quarks) are described by an initial tensor of energy-momentum, for photons (and for gluons!) it is a tensor of Belinfante (F. Hehl, Cologne). This conclusion is very actual in the light of the discussed problem of gluon contribution to the nucleon spin being discussed. The dynamics of spin in gravitational fields and non-inertial reference systems were considered in talks by Yu. Obukhov (IBRAE, Moscow) and A. Silenko (JINR, Dubna). It was shown that particles with spin were the only tester for so-called "torsion" of space-time, and their unitary transformation allow one to pass to a quasi-classical limit and to compare evolutions of quantum spin and classical top.

Calculation of spin and orbital moment contributions on a lattice was discussed in M. Deka's (JINR, Dubna) talk. In particular, essential cancellation of spin and orbital moments of d-quarks was confirmed.

Finally, considerable attention was paid to the history of polarized studies and to further development of the projects of polarization studies at FERMILAB (A. Krisch, Ann Arbor). Plans for further research at the modified accelerator Jlab, as well as plans to create the electron-nuclear colliders in the world: eRHIC, LHeC, MEIC/EIC and especially EIC@HIAF in China were presented by Jian-ping Chen, Newport News.

The program of obtaining of polarized proton and antiproton beams from the decay of Lambda particles at the U-70 IHEP, Protvino, for spin studies at the facility SPASCHARM was presented by S. Nurushev. He stressed the importance of a comparative study of spin effects induced by particles and antiparticles.

Of particular interest were plans to create in IKP (Jülich, Germany), a unique European complex for measurement of the electric dipole moment (EDM) proton and nuclei (N. Nikolaev, Landau ITP). The fact is that the dipole moment of the fundamental particles, if it exists, violates the laws of conservation of spatial and temporal parity. Detection of EDM would indicate violation of the Standard Model and, in particular, would open up the possibility for an approach to the problem of understanding the baryon asymmetry of the Universe. The planned complex will lower the measurement limit of deuteron EDM up to 10^{-29} e·cm.

The talks related to the development of the VBLHEP accelerating complex of JINR were also presented in the program of the conference (V. Ladygin, R. Kurilkin, S. Piyadin, E. Strokovsky – Dubna). They discussed some of the new proposals for research on the basis of the upgraded Nuclotron-M. In particular, the proposal for a new experiment BM@N whose main purpose is to study the properties of dense nuclear matter especially with strange quark participation.

Special plenary and parallel sessions were devoted to the project of the collider complex NICA at JINR. The project has two phases. The first one is the construction of the collider and Multi-Purpose Detector (MPD) for studies of heavy ion collisions to be completed in 2017. The second phase includes the construction of the infrastructure for the acceleration of polarized protons and deuterons in the total energy range 12-27 GeV with luminosity $\geq 10^{32}$ cm^{-2}s^{-1} for protons (talk of A. Kovalenko, Dubna) and a detector for the collision products (SPD) reported by G. Mescheryakov, Dubna. The proposed scheme allows the complex to operate with polarized (longitudinal and transversal) or unpolarized proton

and deuteron beams. The main ideas proposed for the SPD centered around the nucleon spin structure using the Drell-Yan process of lepton pairs (R. Akhunzyanov, Dubna), direct photon (A. Gus'kov, Dubna) and the J/Ψ-mesons production. The possibility of 4π-geometry of SPD for registration of pairs $e^{\pm}$, $\mu^{\pm}$ and direct photons can allow one to measure all leading TMD distribution functions of quarks and antiquarks in the nucleon. Some of them were measured recently in SIDIS experiments, some are still unmeasured. One of the main purposes is to check the fundamental QCD predictions for the change of the sign of the T-odd TMD in the Drell-Yan process compared with that of SIDIS. There were also proposals for the study of spin processes in elastic *pp*-scattering (S. Shimanski and V. Sharov, Dubna), in particular, the so-called "Krisch-effect". Sources of polarized particles and physics of acceleration of polarized beams (Yu. Filatov, Dubna, Yu. and M. Kondratenko, Novosibirsk) were discussed. The spin community presented at the meeting supported plans for a new and unique opportunities for polarization studies at the collider JINR complex. The complex with these features will not have competition with other centers of polarization studies and the data collected will help to solve the riddle of spin effects that has not had solutions since the 70s of the last century.

Special session on the development of the so-called analytic perturbation theory (APT) by Solovtsov-Shirkov was devoted to the blessed memory of Alexander P. Bakulev. As it is known, the effective coupling constant in QCD, $\alpha_s(Q^2)$, has a non-physical pole in the area of 200-300 MeV (the so-called "Landau-Pomeranchuk pole"), which prevents the application of QCD perturbation theory in the region of small momentum transfers. Imposition of an additional condition on the analyticity of divergent series defining $\alpha_s(Q^2)$ eliminates the pole and makes the value of $\alpha_s(Q^2)$ finite up to $Q^2 = 0$. This leads to noticeable stabilization of perturbation theory and to better agreement with experiment up to the small Q^2, e.g. up to GeV^2 for the value of Γ^{p-n} (talks of V. Khandramai, Gomel). Various aspects of the application of this theory as well as a difficult situation in QCD description of transition form factor $F_{\gamma\gamma*\pi}$ were the subject of talks by O. Solovtsova (Gomel), A. Oganesian (ITEP, Moscow), N. Stefanis (Bochum), S. Mikhailov, O. Teryaev, A. Pimikov and D. Shirkov (JINR, Dubna) who have had a long collaboration with A.P. Bakulev.

The summary of the meeting was made in the final report by J. Soffer.

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